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EFFECT OF DICYANDIAMIDE ON GROWTH AND NUTRIENT UPTAKE OF COTTON[1]

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ABSTRACT

The nitrification inhibitor dicyandiamide (DCD) offers potential for improving efficiency of N applications to cotton grown on sandy soils of the southeastern Coastal Plain. Research has indicated that cotton is sensitive to DCD. The purpose of this greenhouse experiment was to investigate the effect of DCD on growth and nutrient uptake of DPL 90 cotton grown for 73 days in pots containing a typical Coastal Plain soil (Norfolk sandy loam, Typic Paleudult). Nitrogen (50 mg kg^{-1}) as $NaNO_3$ or urea, and DCD (0, 2.5, 5, 10, 15 and 20 mg

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thermic, Typic Paleudult) showed erratic responses to preplant-banded applications of urea-containing DCD (J. T. Touchton, 1987, personal communication). Averaged over 3 N rates (67, 101 and 134 kg ha^{-1}), urea formulated with 10% of the N as DCD-N reduced seed cotton yield 30% and 10%, respectively, in 2 years, but increased yield 13% in another year.

The reports of cotton's sensitivity to DCD, as well as yield reductions from ongoing field research, indicate a need for further research regarding DCD's effect on cotton. This investigation was designed to determine the effect of DCD on growth and nutrient uptake of cotton grown in a typical Coastal Plain soil.

MATERIALS AND METHODS

Ten seeds of the cotton cultivar 'Deltapine Acala 90' were planted in separate 22-cm-diameter, 5.45-L plastic containers containing 6.35 kg (oven-dry weight basis) of Norfolk sandy loam which had been sieved through a 2.5-mm screen. The initial soil pH was 5.8, and Mehlich I (7) P, K, Ca, and Mg (8) averaged 39, 76, 325, and 53 mg kg^{-1}, respectively. Organic matter content averaged 10.3 g kg^{-1} and cation exchange capacity averaged 3.6 cmol (+) kg^{-1}. Initial total N and inorganic N averaged 0.38 g kg-1 and 4 mg kg^{-1}, respectively. Ten days prior to planting, 6.0 g of dolomitic limestone (90% calcium carbonate equivalent) was mixed with the soil in each pot and each pot was watered to saturation. Pots were fertilized at planting, and weekly thereafter, with 2X Hoagland's solution (9) minus N. At the first true-leaf stage of development (15 days after emergence), plants were thinned to 3 plants per pot and treatments were applied as aqueous solutions to the soil surface of each pot except the 0-N check pots. Water (0.5 L) was applied to all pots immediately after treatment applications to leach treatments into the soil.

kg^{-1}) were applied to the soil at first true leaf and plants were harvested 58 days later. Sodium nitrate increased leaf dry weight and total dry weight of plants 9.1 and 6.0%, respectively, over urea fertilized plants. Leaf area, dryweight, and stem dry weight were reduced linearly with DCD. Fertilization with urea increased concentrations of leaf P, K, and Mn and reduced the concentration of Mg in leaf tissue. Dicyandiamide increased leaf N, P, and K concentrations but reduced concentrations of Ca, Mg, and Mn. Uptake rates (μg^{-1} g^{-1} fresh root day^{-1}) of Ca and Mg were increased 7.5 and 13.7%, respectively, with $NaNO_3$ vs. urea, while P uptake rate was 15.5% greater for urea-fertilized plants vs. $NaNO_3$-fertilized plants. Dicyandiamide reduced Ca and Mg uptake rates. Phosphorus uptake rates were increased by DCD when urea was the N source. The effects of DCD on cotton growth and nutrient uptake generally resulted from the compound itself and were not an indirect result of nitrification inhibition. Although significant reductions in plant growth did not occur unless DCD exceeded that normally applied with recommended N rates on this soil, these results suggest a need for caution when applying DCD to cotton grown on sandy soils.

INTRODUCTION

Split applications of N are generally used to improve N use efficiency of cotton grown on sandy soils of the southeastern Coastal Plain. The use of nitrification inhibitors, such as dicyandiamide (DCD), with N applied at or near planting might preclude the need for split applications of N on these soils. Dicyandiamide is an effective nitrification inhibitor (1,2) that has been shown to increase yields of winter wheat (2,3) and grain sorghum (4). Greenhouse tests involving DCD applications to cotton indicate that cotton is sensitive to DCD (5,6). Field experiments on a Norfolk sandy loam (fine-loamy, siliceous,

Table 1. Effect of N Source on Growth of Cotton Plants Harvested 67 Days after Emergence.

N Source	Dry wt. Roots	Dry wt. Stems	Dry wt. Leaves	Root fresh wt.	Leaf area	Squares + Blooms
	g				cm^2	Mean No./ Plant
$NaNO_3$	10.56	15.19	13.76	70.30	1681	2.15
Urea	10.19	14.65	12.61	69.56	1592	1.80
$LSD_{0.05}$	1.19	0.71	0.69	5.11	92	0.26
0-N control	3.12	3.24	4.01	23.6	432	0

urea. Nitrogen recovery was less ($P \leq 0.006$) for plants fertilized with urea rather than $NaNO_3$ (95.3 vs. 102.5%). Although precautions were taken to minimize urea hydrolysis and NH_3 volatilization (soil pH in 0-N check pots averaged 6.6 at the end of the experiment and all pots were watered to incorporate treatments into the soil), it is possible that NH_3 volatilization reduced the efficiency of urea.

Plant dry weight decreased linearly as DCD rate increased (Table 2). The decrease was due to reductions in both stem and leaf dry weights. Leaf area was reduced similarly to leaf dry weight (data not shown). Dicyandiamide reduced root fresh weight but did not affect root dry weight (data not shown). There were no DCD X N source interaction effects for any growth variable measured.

Six days after application of 15 or 20 mg kg^{-1} DCD-N cotton leaves developed mottled chlorosis. After 20 days mottled chlorosis developed on leaves of all plants treated with DCD. The chlorosis intensified with DCD-N rate and progressed to necrosis with DCD-N rates > 10 mg kg^{-1}. Symptoms were similar for cotton treated with either N source.

The experimental design was a factorial arrangement of N source X DCD rates in a randomized complete block with 5 replications. Nitrogen sources were urea and $NaNO_3$. Nitrogen rate (apart from DCD-N) was 50 mg kg^{-1} soil. Dicyandiamide rates were 0, 2.5, 5, 10, 15, and 20 mg DCD-N kg^{-1} soil (DCD contains 67% N).

Sixty-seven days after emergence, plants were harvested and separated into leaves, squares + blooms, stems, and roots. Roots were washed of soil, blotted dry, and weighed. Leaf area was determined on a LI-COR LI-3100 area meter (10). All plant organs were then dried for 72 h at 60°C, and weighed and ground to pass a 40-mesh screen. Nitrogen concentrations were determined with a LECO CHN-600 carbon-hydrogen-nitrogen analyzer (12). Apparent N recovery was defined as the difference in N content of all plant tissue in each N-treated pot and the N content of all plant tissue from 0-N control pots. Concentrations of P, K, Ca, Mg, Fe, Mn, Zn, and Cu were determined from wet-ashed samples analyzed with an Inductively Coupled Argon Plasma Spectrophotometer (ICAP).

Statistical analyses included analysis of variance and regression analysis using the General Linear Models (GLM) procedure of SAS (11). Fisher's protected least significant difference (LSD, $\leq P0.05$) was used to separate means among N sources.

RESULTS AND DISCUSSION

Plant Growth and Phytotoxicity Symptoms

Nitrogen applied as $NaNO_3$ increased total dry weight of cotton plants compared to fertilization with urea (data not shown). This increase was primarily the result of an increase in leaf tissue (Table 1). The number of fruiting structures (squares and blooms) per plant was also increased by fertilization with $NaNO_3$ as compared to fertilization with

Table 3. Effect of N Source and DCD on Nutrient Concentrations of Leaf + Square Tissue of Cotton Plants Harvested 67 Days after Emergence.

N Source	N	P	K	Ca	Mg	Mn
	g kg^{-1}					mg kg^{-1}
$NaNO_3$	14.02	1.90	9.92	14.61	3.29	48.9
Urea	14.03	2.41	10.85	14.48	3.05	59.5
$LSD_{0.05}$	0.415	0.115	0.541	0.518	0.126	2.94
DCD-N (mg kg^{-1})						
0	13.18	1.82	9.28	16.06	3.53	59.2
2.5	13.35	2.00	9.76	16.15	3.55	60.0
5	13.41	2.04	9.68	15.11	3.22	55.0
10	14.09	2.29	10.76	14.06	3.00	54.2
15	14.83	2.45	11.04	12.60	2.89	47.9
20	15.32	2.36	11.78	13.26	2.84	48.8
Regression[1] Model	L	L	L	C	Q	L
R^2	0.66	0.31	0.45	0.74	0.61	0.38
0-N check	9.38	2.23	5.32	17.69	3.54	106.4

[1] L, Q, and C = linear, quadratic, and cubic regression model, respectively. All models significant at 0.05 level or greater.

entire plants was not affected by treatments, indicating that no appreciable uptake of mineralized DCD occurred. Apparent N recovery of N apart from DCD-N (N content of treated plants - N content of 0-N check plants) averaged 98% (data not shown).

In general, treatment effects on nutrient concentrations of stem and root tissue were similar to those on leaf + square

Table 2. Effect of DCD on Growth of Cotton Plants Harvested 67 Days after Emergence.

DCD-N	Total Plant Dry wt.	Leaf Dry wt.	Stem Dry wt.	Root Fresh wt.
mg kg^{-1}		g		
0	43.6	14.7	15.8	76.8
2.5	41.0	13.8	15.6	68.6
5	41.4	13.8	15.1	72.8
10	39.6	12.4	14.7	71.4
15	39.1	12.7	14.4	66.4
20	37.8	11.8	13.8	63.7
Regression[1] Model	L	L	L	L
R^2	0.55	0.47	0.60	0.25

[1]L = linear regression model; all models significant at 0.01 level.

Reductions in leaf-dry weight and foliar toxicity symptoms would suggest that the primary site of phytotoxicity of DCD is in leaf tissue and not root tissue. This would agree with data by Amberger and Vilsmeier (12), reporting isolation of DCD taken up by oats and wheat and straw tissue rather than root tissue.

Nutrient Concentrations and Uptake Rates

The 50 mg kg^{-1} N rate and weekly fertilization with 2X Hoaglands solution proved inadequate for cotton grown in this soil volume under greenhouse conditions. Macronutrient concentrations of leaf tissue ranged below that generally considered to be sufficient (Table 3) (13). Total-N content of

Table 4. Effect of N Source and DCD on Ca and Mg Uptake Rates of Cotton Plants Harvested 67 Days after Emergence.

N Source	Uptake Rate	
	Ca	Mg
	---μg g fresh root^{-1} day^{-1}---	
$NaNO_3$	95.0	26.8
Urea	88.4	23.5
$LSD_{0.05}$	4.89	1.76
DCD-N (mg kg^{-1})		
0	97.8	27.0
2.5	106.2	29.1
5	93.1	25.4
10	84.1	22.8
15	84.9	23.8
20	85.0	23.1
Regression[1] Model	L	L
R^2	0.41	0.55
0-N check	86.9	25.3

[1]L = linear regression model; both models significant at 0.01 level.

calculated. Calcium and Mg uptake rates were reduced by fertilization with urea (Table 4). This is in agreement with results demonstrating NH_4^+-N reducing Ca and Mg uptake (16).

Dicyandiamide linearly reduced uptake rates of Ca and Mg (Table 4). The lack of any DCD X N source interactions suggests that reduced Ca and Mg uptake resulted from direct effects of

tissue, with the exception that DCD did not affect concentrations of nutrients in root tissue. Therefore, only leaf + square nutrient concentration data are presented. Both N source and DCD affected leaf macronutrient concentrations (Table 3). Manganese was the only micronutrient affected by either N source or DCD. There were no significant interaction effects on concentrations of any nutrient element in leaf tissue.

Fertilization with urea increased concentrations of P, K, and Mn and reduced the concentration of Mg in leaf tissue (Table 3). The decreased growth resulting from urea fertilization would explain the increases in leaf P, K, and Mn concentrations. In addition, NH_4^+-N uptake from urea would be expected to increase P concentration (14, 15, 16) and reduce concentrations of Ca, Mg, and K (14, 16, 17). The inhibitory effect of NH_4^+-N uptake on K concentrations was diminished by reductions in growth. This accounts for the increased leaf K concentrations in plants fertilized with urea.

Dicyandiamide linearly increased leaf tissue concentrations of N, P, and K and lowered concentrations of Ca, Mg, and Mn (Table 3). Regression analyses indicated a cubic, quadratic, and linear relationship between DCD and concentrations of Ca, Mg, and Mn, respectively. These relationships mirrored those of DCD on plant growth in that DCD effects were minimal until concentrations of DCD-N exceeded 5 mg kg^{-1}. This DCD-N rate would normally be applied with 112 kg-N ha^{-1}, a recommended N rate for cotton on this soil. The increase in N, P, and K concentrations can be attributed to reductions in growth caused by DCD, however, decreases in Ca, Mg, and Mn concentrations cannot be attributed to growth reductions. There were no interaction effects on concentrations of any nutrient element in leaf tissue.

To isolate the effect of DCD on nutrient uptake from the confounding effect of plant growth, nutrient uptake rates were

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Table 5. Effect of N Source and DCD on P Uptake Rate of Cotton Plants Harvested 67 Days after Emergence.

DCD (mg^{-1})	N source	
	$NaNO_3$	Urea
	--P, µg g fresh root^{-1} day^{-1}--	
0	16.3	14.3
2.5	17.1	18.3
5	15.3	18.9
10	16.0	19.5
15	17.1	21.6
20	17.3	21.6
X	16.5	19.1
Regression Model[1]	ns	L
R^2	--	0.60

N Source $LSD_{0.05}$ = 1.15

0-N check = 16.7

[1]ns = no significant treatment effect; L = linear regression model, model significant at 0.01 level.

DCD and not indirect effects caused by inhibition of nitrification and increased NH_4^+-N uptake.

Phosphorus uptake rates were higher with urea than $NaNO_3$ fertilization (Table 5). There was a highly significant ($P \leq 0.01$) DCD x N source interaction on P uptake rate. Dicyandiamide linearly increased P uptake rate when urea was the N source but had no effect on P uptake rate of plants fertilized with NaNO3. The effect is probably due to increased NH_4+-N

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